COMMITTEE OF ENGINEERS, P.W.D. IRRIGATION AND RAILWAYS REPORT 1959 - VCH. A. N. KHOSLA

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PART I

COMPOSITION OF THE COMMITTEE, TERMS OF REFERENCE AND PARTICULARS OF MEETINGS

PART I

COMPOSITION OF THE COMMITTEE, TERMS OF REFERENCE AND PARTICULARS OF MEETINGS

1.01. A large number of bridges including their protection works were designed and constructed in this country in the latter half of the last century on the basis of technical knowledge and with the data then available. Hydraulic Science and technical knowledge in this sphere have since advanced considerably and further data have become available. It was, therefore, considered profitable to review the methods of designs of bridges in the light of the latest knowledge and experience gained and to indicate the standards which should generally guide the design of new bridges in future. With this object in view, the Government of India in the Ministry of Railways decided to set up a committee of engineers to investigate and review the methods of estimating the maximum flood discharge from catchment areas in order to determine the waterway and other connected factors required in connection with the design of bridges.

Composition of the Committee

1.02. Accordingly, the Ministry of Railways, in Resolution No. E57C01/3(RB1) dated March 4, 1957, set up a Committee consisting of:--

Chairman

Dr. A. N. Khosla, Vice-Chancellor, Roorkee University.

Members

Major General R. E. Aserappa, Engineer-in-Chief, Ministry of Defence.

Shri N. K. Roy, Additional Member (Works), Railway Board.

Shri H. P. Sinha, Consulting Engineer (Roads), Ministry of Transport.

Shri D. R. Mehta, Chief Engineer, Central Water & Power Commission.

Secretary

Shri B. C. Ganguli, Joint Director, Civil Engineering, Railway Board.

1.03. Shri B. C. Ganguli, the first Secretary of the Committee, was transferred and Shri D. N. Chopra, Joint Director, was appointed

in his place, *vide* Notification No. E57C01/3(RB1) dated June 21, 1957. Later Shri Chopra was also transferred and Shri N. K. Mehra, Joint Director, was appointed as Secretary, *vide* Notification No. E57C01/3(RBI) dated December 20, 1957.

1.04. As Shri N. K. Roy, Additional Member (Works), Railway Board, proceeded on leave preparatory to retirement and Shri D. R. Mehta, Chief Engineer, Central Water & Power Commission, relinquished charge, their successors Sarvashri D. R. Kohli and R. D. Dhir were nominated in their places, *vide* Notification No. E57C01/3(RBI) dated June 25, 1959.

1.05. The Resolution stated that the Committee would, if necessary, co-opt as members any other engineers with knowledge and practical experience of construction and maintenance of bridges.

The following members were co-opted by the Committee:—

(*i*) Shri S. L. Bazaz, Additional Consulting Engineer (Bridges), Ministry of Transport (Roads Wing). (*ii*) Shri P. R. Ahuja, Director, Central Water & Power Commission.	*Vide* Notification No. E57C01/3 (RB1) dated June 18, 1957.
(*iii*) Shri B.B. Varma, Retired General Manager. (*iv*) Shri P. C. Khanna, Retired Chief Engineer. (*v*) Shri M. R. Venkataram, Retired Chief Engineer. (*vi*) Shri S. D. Banjee, Retired Engineer-in-Chief.	*Vide* Notification No. E57C01/3 (RB 1) dated May 24, 1957.
(*vii*) Shri H. K. L. Sethi, General Manager and Chief Engineer, Ganga Bridge Project, Mokameh.	*Vide* Notification No. E57C01/3 (RB 1) dated March 9, 1958.
(*viii*) Shri N. K. Roy, Retired Additional Member (Works), Railway Board. (*ix*) Shri S. Basu, Director General of Observatories, Indian Meteorological Department.	*Vide* Notification No. E57C01/3 (RB 1) dated July 28, 1959.

1·06 The present composition of the Committee is as under :—

Chairman

Dr. A. N. Khosla, M.P., Vice-Chancellor, Roorkee University.

Members

Major General R. E. Aserappa, Engineer-in-Chief, Ministry of Defence.

Shri N. K. Roy, Retired Additional Member (Works), Railway Board.

Shri H. P. Sinha, Consulting Engineer (Roads), Ministry of Transport.

Shri S. L. Bazaz, Additional Consulting Engineer (Bridges), Ministry of Transport (Roads Wing).

Shri P. R. Ahuja, Chief Engineer (Floods), Central Water & Power Commission.

Shri B. B. Varma, Retired General Manager.

Shri P. C. Khanna, Retired Chief Engineer.

Shri M. R. Venkataram, Retired Chief Engineer.

Shri S. D. Bamjee, Retired Engineer-in-Chief.

Shri H. K. L. Sethi, General Manager & Chief Engineer, Ganga Bridge Project, Mokameh.

Shri D. R. Kohli, Additional Member (Works), Railway Board.

Shri R. D. Dhir, Chief Engineer (Floods), Central Water & Power Commission.

Shri S. Basu, Director General of Observatories, Indian Meteorological Department.

Secretary

Shri N. K. Mehra, Joint Director, Civil Engineering, Railway Board.

Terms of Reference

1.07. The terms of reference of the Committee were as follows:—

(i) to indicate for different regions the method of determining the maximum discharge to design the waterway for bridges. In places where empirical formulae are recommended to be used, the value of constants to be prescribed for guidance;

(ii) to indicate the general principles for determining the extent of bed scour for the design of foundations and the design of training works, the extent of afflux to be permitted at bridge openings for the peak discharge, the minimum free-board for various types and sizes of bridges and waterways to be provided; and

(iii) to indicate measures to ensure safety of railway bridges against failure of various 'Railway affecting' works like tanks, canals, etc

Framework of the Report

1.08. The Report of the Committee has been divided into six parts as under:—

Part I—Composition of the Committee, terms of reference and particulars of meetings.

Part II—Determination of maximum discharge for the design of waterway of bridges.

Part III—Determination of bed scour for the design of foundations and training works, the extent of afflux and the minimum free-board for bridges and determination of waterway required.

Part IV—Organisation for implementing the short-term and the long-term plans referred to in Parts II and III of the report and its functions.

Part V—Measures to ensure safety of railway bridges against failure of various 'Railway affecting' works.

Part VI—Conclusions and summary of recommendations.

1.09. This report deals mainly with catchments of small and medium sizes which present the greatest problems. The principles enunciated herein are, however, generally applicable to catchments of larger sizes as well. For the purpose of this report, catchments up to about 200 square miles are classified as 'small', between 200 and 2,000 square miles as 'medium', between 2,000 and 10,000 square miles as 'large' and above 10,000 square miles as 'very large'.

1.10. The recommendations made in this report are essentially in respect of railway bridges on lines built to 'Main Line' standards. Deviations from these may be necessary and permissible on lines built to lower standards where dislocation of traffic during floods can be tolerated or where suitable safeguards are provided such as restricted train running during floods and/or at night.

Collection of Data

1.11. In December 1956, the Railway Board directed each Railway to set up a cell for reviewing the records of Railway bridges from the initial survey stage right up to the present day, covering the initial design and construction and the history of various floods, repairs, additions and alterations to protection and training works that have been found necessary subsequent to construction, with a view to checking the original design in the light of subsequent experience and knowledge. In March 1957, the Railway Board sanctioned posts

of one Deputy Chief Engineer (Special) for each Railway to take charge of these cells. This organisation was reinforced later by the appointment of four retired Chief Engineers (later co-opted as members of this Committee) assisted by experts from outside the Railways, to provide general guidance to the Deputy Chief Engineers (Special).

1.12. In order to provide representative and useful data as a basis for further study, the Committee felt that there was an urgent need for taking discharge observations at some existing bridge sites on some selected typical streams in each region, by measuring velocities, cross-sections, high flood levels etc. and recording of daily rainfall as well as the hourly intensities of rainfall in the catchments of the selected streams during floods. Accordingly, in March 1957, the Committee requested each Railway to collect the necessary data. The Committee is pleased to note that a considerable volume of useful data has been collected during the last two monsoons and further collection of data is being continued.

1.13. With a view to collecting all relevant data available in the country, the Committee prepared and sent a detailed questionnaire (Appendix A) to all State Governments, Railways and other concerned organisations. As a result, considerable data were obtained and examined but in view of the complexity of the problem, the data collected were found to be inadequate for the Committee to draw any specific conclusions.

State Committee of Engineers

1.14. The Committee is also pleased to note that the Railway Board, *vide* their letter No. 57/W2/CMT/20 dated 23rd June, 1957 (Appendix B), issued orders for setting up a State Committee of Engineers in each State, consisting of senior officers from the Railways, Public Works, Irrigation, Forests and Local Self-Government Departments of the State Governments, for carrying out a periodical review of the position of flood affecting works.

Meetings of the Committee

1.15. The following meetings were held by the Committee:—

1st *meeting*—at New Delhi on 6th March, 1957; attended by Dr. A. N. Khosla, Major General R. E. Aserappa, Sarvashri N. K. Roy, H. P. Sinha, D. R. Mehta and B. C. Ganguli.

2nd *meeting*—at New Delhi on 29th April, 1957; attended by Dr. A. N. Khosla, Major General R. E. Aserappa, Sarvashri N. K. Roy, H. P. Sinha, D. R. Mehta, P. R. Ahuja and B. C. Ganguli.

3rd meeting—at Roorkee on 3rd July, 1957; attended by Dr. A. N. Khosla, Sarvashri N. K. Roy, H. P. Sinha, D. R. Mehta, S. L. Bazaz, P. R. Ahuja, P. C. Khanna and D. N. Chopra.

4th meeting—at New Delhi on 21st September, 1957; attended by Dr. A. N. Khosla, Major General R. E. Aserappa, Sarvashri N. K. Roy, H. P. Sinha, D. R. Mehta, S. L. Bazaz, P. R. Ahuja, B. B. Varma, P. C. Khanna, M. R. Venkataram, S. D. Bamjee and D. N. Chopra.

5th meeting—at Hyderabad from 2nd to 4th December, 1957; attended by Dr. A. N. Khosla, Major General R. E. Aserappa, Sarvashri N. K. Roy, P. R. Ahuja, B. B. Varma, P. C. Khanna and N. K. Mehra.

6th meeting—at New Delhi on 4th February, 1958; attended by Dr. A. N. Khosla, Major General R. E. Aserappa, Sarvashri N. K. Roy, H. P. Sinha, S. L. Bazaz, P. C. Khanna, M. R. Venkataram, S. D. Bamjee and N. K. Mehra.

At this meeting, it was decided to set up a Drafting Sub-Committee, consisting of Major General R. E. Aserappa, and Sarvashri S. L. Bazaz and P. R. Ahuja with Shri N. K. Mehra as Secretary. The Drafting Sub-Committee has held the following meetings:—

1st meeting—at New Delhi on June 14, 1958; attended by Major General R. E. Aserappa, Sarvashri H. P. Sinha, S. L. Bazaz, P. R. Ahuja and N. K. Mehra.

2nd meeting—at Srinagar on 25th and 26th June, 1958; attended by Dr. A. N. Khosla, Major General R. E. Aserappa, Sarvashri S. L. Bazaz, P. R. Ahuja and N. K. Mehra.

3rd meeting—at New Delhi on 3rd, 4th and 5th July, 1959; attended by Dr. A. N. Khosla, Sarvashri N. K. Roy, S. L. Bazaz, P. R. Ahuja, P. C. Khanna and N. K. Mehra.

4th meeting—at New Delhi on 28th July, 1959, attended by Dr. A. N. Khosla, Major General R. E. Aserappa, Sarvashri N. K. Roy, H. P. Sinha, S. L. Bazaz, P. C. Khanna, and N. K. Mehra.

7th meeting—at New Delhi on 29th, 30th and 31st July, 1959; attended by Dr. A. N. Khosla, Major General R. E. Aserappa, Sarvashri N. K. Roy, H. P. Sinha, S. L.

Bazaz, P. R. Ahuja, B. B. Varma, P. C. Khanna, H. K. L. Sethi, D. R. Kohli, R. D. Dhir and N. K. Mehra.

8th meeting—at New Delhi on 5th September, 1959; attended by Dr. A. N. Khosla, Major General R. E. Aserappa, Sarvashri N. K. Roy, H. P. Sinha, S. L. Bazaz, P. R. Ahuja, B. B. Varma, P. C. Khanna, H. K. L. Sethi, D. R. Kohli and N. K. Mehra.

At this meeting, it was decided to set up a Drafting Sub-Committee, consisting of Major General R. E. Aserappa, Shri S. L. Bazaz and Shri N. K. Mehra. The Drafting Sub-Committee has held the following meetings:—

1st meeting—at New Delhi on 7th September, 1959, attended by Major General R. E. Aserappa, Shri S. L. Bazaz and Shri N. K. Mehra.

2nd meeting—at New Delhi on 8th September, 1959, attended by Major General R. E. Aserappa, Shri S. L. Bazaz and Shri N. K. Mehra.

3rd meeting—at New Delhi on 9th September, 1959, attended by Major General R. E. Aserappa, Shri S. L. Bazaz and Shri N. K. Mehra.

9th meeting—at New Delhi on 15th September, 1959, attended by Dr. A. N. Khosla, Major General R. E. Aserappa, Sarvashri N. K. Roy, H. P. Sinha, P. R. Ahuja, B. B. Varma, M. R. Venkataram, H. K. L. Sethi, D. R. Kohli, R. D. Dhir, S. Basu and N. K. Mehra.

10th meeting—at New Delhi on 30th September, 1959; attended by Dr. A. N. Khosla, Major General R. E. Aserappa, Sarvashri N. K. Roy, S. L. Bazaz, P. R. Ahuja, B. B. Varma, P. C. Khanna, S. D. Bamjee, H. K. L. Sethi, D. R. Kholi, S. Basu and N. K. Mehra.

Acknowledgments

1.16. The Committee wishes to acknowledge the valuable assistance rendered by Sarvashri B. N. Ghosh, A. K. Chakravarti and Gurdial Singh of the Indian Railways and specially of Captain L. V. Ramakrishna of the Engineer-in-Chief's Branch, Ministry of Defence. The Committee also wishes to record its appreciation of the very useful work done by its Secretaries, Sarvashri B. C. Ganguli and D. N. Chopra, Ex-Joint Directors of the Railway Board, and specially by the present Secretary, Shri N. K. Mehra, Joint Director, Railway Board, all of whom shouldered this burden of responsibility in addition to their full time normal duties.

PART II

DETERMINATION OF MAXIMUM DISCHARGE FOR THE DESIGN OF WATERWAY OF BRIDGES

PART II

DETERMINATION OF MAXIMUM DISCHARGE FOR THE DESIGN OF WATERWAY OF BRIDGES

First term of Reference

2.01. The characteristics of natural drainage basins and meteorological influences affecting run-off are too complex and variable to be evaluated accurately by computational procedures or indeed by any other methods. Even if it were practically feasible to analyse these characteristics with scientific accuracy, the limitations of basic data would generally affect such studies. The reliability of the estimates of run-off is dependent as much upon the soundness of judgment used in the interpretation of data as on the accuracy of the computational procedures adopted. A thorough study of the characteristics and meteorological factors affecting run-off from a specific basin, constitutes an essential basis for sound judgment and particularly so, when flood waters from two adjacent basins intermingle, in which case the evaluation of discharge is more difficult.

Factors Affecting Run-Off

2.02. The main factors which affect flood run-off are given below and the degree to which the relative influences of these factors can be assessed will govern the degree of accuracy of the estimates of run-off.

(a) *Drainage basin factors.*

- (i) Size, shape, slope and orientation of basin;
- (ii) Location with respect to storm path;
- (iii) Nature of soil, condition of vegetation, moisture content of the soil, infiltration characteristics;
- (iv) Extent of surface storage in lakes and swamps;
- (v) Condition, slope, capacity and configuration of the main stream and its tributaries.

(b) *Storm factors.*

- (i) Intensity, duration and sequence of rainfall;
- (ii) Distribution over the catchment area during successive time intervals;
- (iii) Direction of prevailing winds.

Evolution of Empirical Formulae

2.03. In view of the complexity of the various factors involved, many workers in the field of Hydrology have tried to derive certain empirical formulae for the determination of the maximum flood discharge from a basin. The common feature of all these empirical formulae is that they take into consideration only one or two of the factors affecting run-off as variables, and try to cater for the effect of all the other factors by introducing a constant whose value is varied to suit the conditions obtaining in a particular region. The choice of the value of the constant is based mostly on past practice in the region and on the judgment and experience of the engineer. The biggest drawback of all these empirical formulae is that the accuracy of the maximum flood discharge so determined is completely dependent on the correct choice of the value of the constant used.

Current Practice in India

2.04. The present practice for the design of bridges in India is to calculate the maximum discharge from the best available information about the highest flood level and the survey of the cross-sectional area of the stream and its slope. The figures so derived are checked against the value obtained on the basis of an empirical formula prevalent in the region. The designer has then to exercise his judgment as to a figure which should be adopted for design, bearing in mind all other relevant factors. The empirical formulae commonly used for the determination of the maximum flood discharge are the following:—

(a) *Dicken's formula*

$Q=CA^{\frac{3}{4}}$ where Q = Maximum flood discharge in cusecs ;
A = Area of catchment in square miles ;
C = A coefficient usually varying from 400 to 1400.

This formula is used widely in North and Central India.

(b) *Ryve's formula*

$Q=CA^{\frac{2}{3}}$ where Q = Maximum flood discharge in cusecs ;
A = Area of catchment in square miles ;
C = A coefficient usually varying from 450 to 2700.

This formula is widely used in South India.

(c) *Inglis' formula*

$Q=\frac{7000A}{\sqrt{A+4}}$ where Q = Maximum flood discharge in cusecs ;
A = Catchment area in square miles.

This formula is used in the Western Ghat region.

(*d*) *Rational formula*

$Q = 640\,CIA$ where Q = Maximum discharge in cusecs ;
A = Catchment area in square miles ;
I = Intensity of rainfall anticipated in inches per hour, for the duration of the time of concentration ;
C = Coefficient of surface run-off giving the proportion of rainfall that may be expected to flow off the surface.

The values of 'C' as commonly assumed are :—

Steep, bare rock, city pavements	0·90
Rock, steep but wooded	0·80
Plateaus, lightly covered	0·70
Clayey soils, stiff and bare	0·60
Clayey soils, lightly covered	0·50
Loam, lightly cultivated or covered	0·40
Loam, largerly cultivated	0·30
Sandy soil, light growth	0·20
Sandy soil, covered, heavy brush	0·10

This formula is used for small catchments where the intensity of storm can be taken to be uniform over the whole area.

A complete list of the various empirical formulae in vogue in various parts of the world is given in the paper 'Estimation of Design Flood' by Sarvashri R. D. Dhir, P. R. Ahuja and K. Krishnamurthy of the Central Water & Power Commission.

Need for a better Approach

2.05. As already explained in paragraph 2.03, the results obtained by the use of empirical formulae cannot be wholly satisfactory. Hence the necessity is felt for a better approach to the problem based on the latest developments in the science of Hydrology and technical knowledge. But a good deal of basic data regarding discharges and rainfall over long periods are necessary for this purpose. At present, only daily rainfall data are available from a skeleton network of rain-gauge stations, although some of these stations were established about 60 years ago. Also, the coverage of this skeleton network is relatively small and quite inadequate in many parts of the country for estimating the run-off from catchments of medium and small streams. The number of automatic rain-gauges at present installed is very small and hence very insufficient data are available regarding the intensities of rainfall for durations shorter than 24 hours.

As regards stream gauge and discharge data, while these are available for some of the major rivers for limited periods, relatively little data are available for medium and small streams.

Necessity for two Plans

2.06. In order to arrive at better results, collection of requisite data should be started immediately in accordance with a systematic plan to cover the entire country. A very large number of automatic rain-gauges and automatic stream-gauges has to be installed. As the process of collection of data obviously takes time, the evolution of a revised approach for the determination of flood discharge for the design of waterway of bridges will have to be considered as a long-term measure. But a short-term plan, based on available data or data that can be readily collected, is proposed with a view to improving the present approach, as soon as possible. In the meantime, however, the existing practices as obtaining in different regions have to continue.

Design Flood Discharge

2.07. The magnitude of flood discharge for the purpose of design of waterway for bridges is determined by two main considerations, namely hydraulic and economic. Between these two a balance has to be struck. It would not be economical, even if it were feasible, to design a bridge to ensure complete security against the 'maximum flood ever'. A bridge with an unnecessary large waterway, can have the disadvantage of the river meandering through the waterway and silting up part of it, resulting in the full section of the waterway not being available for the flow during a very high flood and in undue concentration of flow in some sections. The correct balance would obviously be to provide optimum waterway with permissible afflux.

2.08. A very important factor in determining the magnitude of run-off, for which a waterway is to be designed, is that of the time element or periodic expectancy of flood flows. Unfortunately, stream flow records cover only a comparatively short period in recent years and do not yet permit establishing a dependable flood cycle, even if such a cycle actually exists. For convenience, floods of different magnitudes have been classified as 1-year, 10-year, 100-year or 1,000-year floods, but this concept is entirely statistical. It has to be kept in mind that the 100-year flood may occur any time, followed after a few years possibly by the 1,000-year flood. In spite of the fact that no assurance can be had as to when the so-called 100 or 1,000-year floods will occur, a flood of some fixed return period must be selected for design.

2.09. The Committee is of the opinion that the 'design-flood' or 'design-discharge' (the discharge for which the waterway is to be designed) should be the maximum flood on record for a period of not less than 50 years. Where adequate records are available,

extending over a period not much less than 50 years, the 'design-flood' should be the 50-year flood determined from the probability curve prepared on the basis of the recorded floods during that period. In cases where requisite data are not available for particular streams, as for bridges on new lines to be constructed, the 'design-flood' should be based on the highest recorded flood in the neighbouring or other catchments of similar size and ground and meteorological characteristics.

2.10. A flood discharge of a higher magnitude than the design-discharge can occur during the life time of the bridge. It would, therefore, be prudent to provide for an adequate margin of safety and to design the foundations and protection works for a larger discharge. For the time being, an empirical approach would be to add to the 'design-flood' a percentage of its discharge to get this larger flood for which foundations and protection works should be designed. This percentage may be 30 per cent. for small catchments up to 200 square miles, 25 per cent. to 20 per cent. (decreasing with increase in area) for medium catchments of 200 to 2,000 square miles, 20 per cent to 10 per cent. for large catchments of 2,000 to 10,000 square miles and less than 10 per cent, at the discretion of the engineer, for very large catchments above 10,000 square miles.

2.11. This larger flood for which the foundations and protection works are to be designed would hereafter be referred to as the 'foundation design-discharge'.

2.12. At this stage, it would be desirable to bring in the concept of the 'maximum possible flood', *i.e.*, the flood which may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the region. A close approximation to the magnitude of such a flood will not be possible until adequate meteorological and hydrological data become available and are analysed in sufficient detail. This 'maximum possible flood' may be no more than the 'foundation design-flood' mentioned above or it may be in excess of that flood. The relationship between these two might well be worked out in the short-term plan, if possible, but certainly in the long-term plan.

2.13. In cases where the 'maximum possible discharge' is appreciably in excess of the 'foundation design-discharge', it may be neither economical nor otherwise desirable in many cases to design bridge foundations and protection works to cater for the 'maximum possible discharge'. For very important bridges, however, this matter will have to be carefully considered by the engineer-in-charge who may decide to cater for the 'maximum possible discharge' or a lesser discharge depending on economic and other considerations.

Short-term Plan

2.14. As brought out in paragraph 2.06, a short-term plan for the determination of discharge for the design of waterway in bridges has to be evolved on the basis of available data or data that can be readily collected. Pending availability of adequate data under the long-term plan, resort has to be taken to the use of empirical formulae for the determination of flood discharge, as a check against the results obtained by field methods. As no one empirical formula possesses any inherent scientific advantage over the other and as it would be desirable to get a unified practice in India for the purposes of comparative study, it is recommended that only one selected simple formula should be evolved for the whole of India, with the range in the value of the coefficient reduced to the minimum possible. This task should be entrusted to the 'Special Bridge Engineer' suggested in paragraph 4.06. If it is not possible to evolve one such formula, then two or more formulae, including Dicken's, which is most widely used in India at present, may be recommended for adoption.

2.15. With the scanty data available at present, it will be premature for this Committee to attempt to evolve a new formula for general application or to work out values of the coefficient for any of the existing formulae or to recommend any ad-hoc figures at this stage.

2.16. India is a vast country with widely varying rainfall and topographical charactertistics. Hence great care has to be exercised in the choice of the value of the coefficient (C) to be used in any formula. Some of the most important factors affecting run-off are the size and slope of the catchment, nature of soil and rainfall pattern. It is suggested that India should be divided into various regions and sub-regions of similar hydro-meteorological characteristics (Maps giving topography, hydrographical features and rainfall pattern of the country, as shown in plates 3, 5 and 6 of the National Atlas of India, are at Appendices 'C', 'D' and 'E'). For each region the value of 'C' to be used should be worked out for different slopes and sizes of the catchments.

2.17 For a satisfactory determination of the values of 'C', a practical approach would be to observe actual flood discharges at a large number of representative bridges, covering the whole country and to correlate these discharges with the size, slope and nature of catchments, rainfall pattern etc. In most cases these observations would not correspond to the highest flood level but the discharge at the highest flood level can be calculated with a fair degree of accuracy from the gauge-discharge curve based on these observations. The highest flood level marks exist on most of the bridges. The correlation between the design-discharge and the size of the

catchment can then be represented in the form of a formula with varying constants or in the form of graphs and charts.

2.18 The observation of actual discharges at bridges will be a continuous process and the values of 'C' as obtained above should be reviewed and revised from time to time in the light of further experience.

2.19 A more exact determination of the design-flood will be possible under the long-term plan, when more data have been collected and analysed on scientific lines.

Long-term Plan

2.20. Rainfall and run-off are inter-related in a complex manner and a thorough study of these two factors is necessary for any scientific analysis to arrive at the maximum flood discharge. Run-off can be considered in volume, that is, the volume of water that will be available as stream flow in a period of time, say a month or a year, as a result of rainfall during that period. Run-off can also be considered in intensity, that is, the momentary discharge or flood peak that will result from a certain pattern of rainfall at the time. It is the latter concept which concerns the design of bridges. A thorough study of run-off (intensity) in relation to rainfall is, therefore, necessary to be able to determine the magnitude of the maximum flood discharge. The first essential, for the purpose, would be a comprehensive study of the rainfall pattern of the country.

Study of Rainfall

2.21. Based on an analysis of the data from the self-recording rain-gauges, intensity-frequency rainfall charts for short durations should be evolved for the whole of India somewhat on the lines of David L. Yarnell's work for the United States Department of Agriculture. A start has already been made in this direction by the Indian Meteorological Department. It is suggested that charts be prepared indicating rainfall intensities covering periods of five minutes, ten minutes, thirty minutes, one hour, two hours, four hours, eight hours, sixteen hours and twenty-four hours of rainfall with return periods of 2 years, 5 years, 10 years, 25 years, 50 years and 100 years for different areas. For this purpose, the data from non-recording rain-gauges also can be split up to give intensities for periods less than 24 hours on the analogy of the self-recording rain-gauges in the vicinity.

Design-storm

2.22. When these rainfall intensity-frequency charts are available. the magnitude of the design-storm, i.e., the storm which gives rise

to the design-flood for the particular catchment, can be chosen based on its time of concentration and the desired frequency of occurrence for which the structure is to be designed. The duration of rainfall chosen should be equal to the time of concentration of the basin.

Time of Concentration

2.23. Time of concentration is the time taken by the run-off from the farthest point on the periphery of the catchment to reach the discharge site. The following are some of the methods in vogue for the determination of the time of concentration:—

(*a*) *Bransby-Williams formula*

$$T = \frac{0 \cdot 9 \times L}{\sqrt[10]{M} \times \sqrt[5]{H}}$$

Where T = time of concentration in hours ;
L = the length of the stream —source to site (miles) ;
H = average grade—source to site (per cent), to be determined from 'L' and difference in levels between source and site ;
M = catchment area in square miles.

This empirical formula is being widely used by the Department of Main Roads, Australia.

(*b*) ***Formula used by State of California***

$$T = \left(\frac{11 \cdot 9 \times L}{H}\right)^{0 \cdot 385}$$

Where T = time of concentration in hours ;
L = distance from the farthest point in the catchment to the culvert in miles ;
H = fall in level from the farthest point to the culvert in feet.

This formula was recommended for use in India by Sri Goverdhanlal of the Roads Wing (Ministry of Transport) in his paper No. 167 in the Indian Roads Congress Journal of December, 1953.

Either or both of the above formulae can be used and the final value of the time of concentration decided, based upon the engineer's judgment.

Design Flood Discharge

2.24. The magnitude of the design-flood may be worked out on the basis of direct observations as indicated in paragraph 2.17.

2.25. On the basis of the design-storm, the design-flood may be obtained, among others, by any of the following methods:—

(a) *Direct correlation by graphs*

By an analysis of the rainfall and corresponding run-off on different types and sizes of catchments, graphical correlations can be obtained from which the peak discharge can be directly read, when the size, mean-slope and design-storm are known. Graphs for the determination of the 'design-flood' discharge could be prepared on the same lines as those given by the U.S. Department of Commerce, Bureau of Public Roads in 'A Simplified Method for the Hydraulic Design of Culverts'. This would be suitable for small catchments upto about 20 square miles in area.

(b) *Use of Rational formula*

$Q = 640\ CIA$ Where
- Q = maximum discharge in cusecs ;
- A = catchment area in square miles ;
- I = intensity of rainfall anticipated, in inches per hour, for the duration of the time of concentration ;
- C = coefficient of surface run-off giving the proportion of rainfall that may be expected to flow off the surface.

The value of the coefficient 'C' depends upon the characteristics of the drainage area. By a study of the rainfall and discharge observations in the various catchments, coefficients can be evolved for use on different types of catchments and different soil conditions.

This method will be specially suitable for catchments less than 200 square miles in area. In view, however, of a set pattern of monsoon rainfall in India, it may be permissible to extend this method to larger areas. Such extension will not be permissible in regions where the pattern of rainfall changes erratically.

(c) *Unit Hydrograph Method*

For catchment areas ranging from 200 to 2,000 square miles in area. a satisfactory method for the determination of flood discharge is the Unit Hydrograph Method, as it is based on an observed relation between rainfall and flood flow thus automatically taking into account the topographic and other characteristics of the basin. Its success is also due to the fact that it is the best method that can be followed where the number of flood discharge observations is comparatively small but where long-term rainfall data are available. A basic assumption in this method is that the design storm used for determining flood run-off is uniformly distributed over the entire area under consideration.

PART III

DETERMINATION OF BED SCOUR FOR THE DESIGN OF FOUNDATIONS AND TRAINING WORKS, THE EXTENT OF AFFLUX AND THE MINIMUM FREE-BOARD FOR BRIDGES AND DETERMINATION OF WATERWAY REQUIRED

(d) *Unit hydrograph in combination with flood routing methods.*

For catchment areas larger than 2,000 square miles, the inherent limitations pointed out in the above paragraph, are largely overcome by dividing the whole area into sub-areas and considering the unit hydrographs for each sub-area separately, so as to take into account the effect of variations in the area-wise distribution of rainfall. The different sub-area hydrographs are computed and combined with proper time relation to obtain the composite hydrograph.

2.26. In addition, it is recommended that the advances being made in the other countries in this direction should be carefully and constantly studied.

Observation of actual Discharges at Bridges

2.27. The Committee would like to sound a note of warning against attaching too much importance to empirical formulae or purely theoretical studies. The main basis for the determination of discharge must remain the observed data where available, which should continue to be collected and published both in the short-term and the long-term plans. Empirical formulae should be used only as a guide and the results obtained from them modified in the light of other known data and experience as these become available.

PART III

DETERMINATION OF BED SCOUR FOR THE DESIGN OF FOUNDATIONS AND TRAINING WORKS, THE EXTENT OF AFFLUX AND THE MINIMUM FREE-BOARD FOR BRIDGES AND DETERMINATION OF WATERWAY REQUIRED

Second Term of Reference

3.01. This Term of Reference pertains to the basic principles governing the design, construction and maintenance of bridges. Apart from the publication of "River Training and Control on the Guide Bank System of the great alluvial rivers" by Francis J. E. Spring in 1903, there have been three noteworthy contributions which have brought about significant advances in the design of channels and of hydraulic structures, namely, Kennedy's "Prevention of Silting in Irrigation Canals" (1895), Lacey's "Design of Stable Channels in Alluvium" (1930) and Khosla's "Design of Weirs on Permeable Foundations" (1936). The design of foundations, of training and protective works and of approach and outfall channels of bridges over streams in alluvium are mainly based on these classics and no major modifications in the basic concepts set forth therein have been suggested by subsequent workers in this field. However, there appears to be need for further investigation and research on river regimes, guide banks and protective works, and the behaviour of existing hydraulic structures, in order to be able to assess the adequacy of existing theory and current practice and to suggest modifications where called for and thereby bring up-to-date the information and knowledge contained in the above-mentioned classics and other related works.

3.02. The Committee has separately made recommendations in Part IV, outlining the scope of such investigations and research and the constitution and functions of a body to be set up for the purpose.

3.03. The design practice in respect of hydraulic structures varies considerably in different engineering organisations and even in similar organisations in different States mainly because of a lack of co-ordination in respect of interpretation of different hydraulic theories and the assessment of the behaviour of existing structures in the various regions. In the paragraphs that follow, the Committee has attempted to interpret these theories on the basis of sound practice

which has stood the test of time, to focus attention on fundamentals and to evolve uniformity of practice. The correct application of these in actual practice will, however, largely depend on the judgment of the engineer, responsible for the design, on the basis of his mature experience.

Design of Waterway

3.04. The determination of discharge for which the waterway of a bridge has to be designed, has been dealt with in Part II. The waterway for this design-discharge has to be determined from the following two main considerations:—

(*i*) Insufficient waterway will lead to undue concentration of flow resulting in dangerous scour requiring deeper and, therefore, costlier foundations, harmful afflux involving submergence of more area and property upstream of the bridge, and expensive protective works.

(*ii*) Excessive waterway will involve greater initial cost of the bridge and result in harmful shoaling and dangerous meanders of the stream immediately upstream of the bridge. In such cases, there will be oblique flow and unequal distribution of discharge with consequent heavy concentration of flow and deep scour in some sections of the bridge resulting in increased maintenance costs.

3.05. The problem is to strike the correct balance between these two opposing considerations. This will largely be a matter of judgment based on experience. It is, however, possible to lay down some broad principles for determining the correct balance.

3.06. In the case of a river which flows between stable high banks, and which has the whole of the bank to bank width functioning actively in high floods, the waterway to be provided should be practically equal to the width of the water-spread between the stable banks at the design-flood level. This will hold even if such a river slightly overtops its banks during extraordinary floods. If, however, the depth of spill on the banks is appreciable, the waterway should be suitably increased beyond the bank to bank width as any undue constriction of the waterway is likely to result in harmful afflux or scour.

3.07. On a river having a comparatively wide and shallow section, and having the active channel in high floods confined only to a portion of the full width from bank to bank, a constriction of the natural waterway would normally be desirable both from hydraulic and economic considerations.

3.08. For rivers with alluvial beds, the waterway should normally be equal to the width given by the Lacey's formula—

$Pw = C\sqrt{Q}$ where Pw = the wetted perimeter (in feet) which may be taken as the effective width of waterway in the case of large streams ;

Q = the design-discharge (in cusecs) for the bridge ;

C = a constant normally equal to 2·67, but which may be varied to suit the nature of bed material and the characteristics of the flood flow.

If the bed material consists of incoherent alluvium down to the maximum depth of scour, and if the high flood is likely to last for a long time enabling near regime conditions of flow to be established, the constant may be taken as 2.67.

3.09. If the river is of a flashy nature and the bed material does not submit readily to the scouring effect of the flood, Lacey's formula will not apply. In such cases, the waterway should be determined by the area-velocity method, the depth being ascertained taking into consideration the design-flood level, maximum depth of observed scour and characteristics of the bed material.

3.10. For rivers in sub-montane stages, where the bed slopes are steep and the bed material ranges from heavy boulders to gravel, it is not possible to lay down any hard and fast rules about the degree of restriction in the natural waterway. In such cases, this restriction will be governed largely by the configuration of the active channel or channels, the cost involved in diversion and training of these channels, and the cost of the guide banks which will need much heavier protection than the normal type of guide banks required for rivers with alluvial beds.

3.11. The waterway of the bridge will be the aggregate clear waterway in the various spans, *i.e.*, the distance from face to face of abutments less the aggregate width of the piers. Suitable allowance may be made for restriction in waterway caused by pitching or stone protection, if any, round the piers and at abutments.

Depth of Scour

3.12. The probable depth of scour will mainly determine the depth to which the foundations of a bridge must be taken in alluvial beds. The sub-soil available at and below the foundation level should be capable of bearing safely the pressures resulting from the dead load of the bridge structure with the worst combination of live loads, wind loads, and other forces for which the bridge has to be designed in accordance with the code of practice.

3.13. For rivers flowing in rocky or other types of inerodable beds, the scour of the bed is obviously not a problem.

3.14. For rivers flowing in alluvium, the normal depth of scour may be estimated by Lacey's formula—

$D = 0{\cdot}473 \left(\frac{Q}{f}\right)^{\frac{1}{3}}$ where

D = normal depth of scour (in feet) measured from the level of the 'foundation design-flood';

Q = 'foundation design-flood' discharge (in cusecs) ;

f = Lacey's silt factor.

Again attention is drawn to the fact that this formula is applicable to cases where the bed consists of incoherent alluvial materials down to the maximum depth of scour.

3.15. It is suggested that investigations be undertaken to establish relationship between scour depth and flood discharge in gravel and boulder beds and in coherent materials.

3.16. In case the width of a bridge is less than Pw in Lacey's formula ($Pw = 2.67 \sqrt{Q}$, where Q is the 'foundation design-flood' discharge) and in areas of concentration of flow, it will be safer to work out the depth of scour for the discharge per foot run (q) instead of the total discharge (Q). This will generally be the case as the width of waterway has been recommended to be fixed on the basis of the design-discharge, which in most cases will be less than the 'foundation design-flood' discharge. Thus the scour depth will generally have to be determined from the discharge per foot run.

3.17. The relationship between scour depth (D) and discharge per foot run (q) can be deduced from the Lacey's equation given above and may be written as—

$$D = 0.9 \left(\frac{q^2}{f}\right)^{\frac{1}{3}}$$

3.18. Kennedy's formula for depth of scour can be deduced in standard sands (f = 1) from his equation for critical velocity (Vo) and hydraulic mean depth D, namely,

$$Vo = 0{\cdot}84\, D^{0.64}$$

where

D = the hydraulic mean depth which will also be the depth of scour for the critical velocity ;

Vo = the critical velocity, which is neither silting nor scouring.

In terms of discharge per foot run, this equation can be written as:

$$D = 1.1 q^{0.61}$$

Both Lacey's and Kennedy's formulae give very nearly the same results for depth of scour (D) for a given discharge per foot run (q) and f = 1.

3.19. Quantitatively, scours may be classified as follows:—

Class A—Straight reach	1.25 D
Class B—Moderate bend	1.50 D
Class C—Severe bend	1.75 D
Class D—Right angle bend	2.00 D
Class E—Severe Swirls	2.50 D

This quantitative classification is in keeping with the observations taken on existing bridges and barrages founded on alluvium. Scours classed D and E are likely to occur at the noses of piers and guide banks respectively. The pier foundations should, therefore, be taken to twice the depth of normal scour plus a further depth for grip. In the Code of Practice for road bridges, it has been recommended that the minimum depth of foundation below the highest flood level shall be 1.33 D′ where D′ is the anticipated maximum depth of scour below H.F.L. including that on account of possible concentration of flow. As explained above, this D′ should be taken as twice the normal depth of scour D. It is recommended that the foundations be taken to a depth not less than 1.33 D′ below the level corresponding to the 'foundation design-flood' for all bridges unless other measures of protection, such as pucca floors, curtain walls, apron and pitching, are provided. Further research in this connection both for Railway and road bridges should be carried out. This may, in the first instance, be undertaken by the 'Special Bridge Engineer' to be appointed (paragraph 4.06) and later continued in the long-term plan.

3.20. Records of depths of scour at a large number of railway and road bridges and barrages on the major rivers in India exist over a long period of years. These observations of scour may not necessarily have been taken at the highest possible flood or even at the highest flood of the season. It will be of the utmost assistance if these records of scour are suitably collected and analysed in relation to the corresponding flood discharge, the direction of flow in relation to the axis of the bridge and the class of bed material. Such analysis may confirm the above assumptions or indicate modifications.

3.21. It must be clearly understood that while the waterway of a bridge may be designed for the maximum flood on record or a 50-year flood, whichever is greater, the design of the sub-structure must be worked out on the basis of scour that could occur during the 'foundation design-flood'. In other words, the foundations must be designed for the extreme conditions which will occur during the 'foundation design-flood' and not only for those occurring during the design-flood.

3.22. The depth of foundations below the deepest scour, or the depth of grip in incohcrent material should be fixcd in such a way that the passive resistance of the sub-soil, which may be callcd into play in that depth of grip, can overcome, with a factor of safety of at least two, the resultant of the worst combination of live loads, horizontal forces like wind loads, tractive effort and braking effort, forces due to water current etc., for which the bridge is to be designed. Should hard material be available at a lcvel above the maximum depth of grip, the foundations may be lcft at that level. The character of the sub-soil available at the depth fixed from the consideration of scour alone should be ascertained by actual borings. The borings should extend for a depth below the designed foundation level at least equal to the smaller dimension of the foundation, unless a hard stratum of reasonable thickness is available at a lesser depth. If the stratum at the designed depth can support the superimposed load safely and without undue settlement, the foundations may be laid at that depth. Otherwise, the depth will have to be increased to reach a stratum which can safely support the superimposed load. Even if the character of the sub-soil at the proposed depth of foundation is suitable, the foundations may have to be taken down deeper, if the existence of a layer of soft material is revealed by the borings immediately at or a short depth below the proposed foundation level.

Afflux

3.23. By afflux is meant the rise in the flood level of the river upstream of a bridge, as a result of the obstruction to natural flow caused by the construction of the bridgc. The amount of afflux will govern the dynamic action of the water. The greater the afflux, the greater will be the difference in levels from upstream to downstream and, therefore, the greater will bc the velocity of flow and the maximum depth of scour; consequently, the greater will be the depth to which the foundations, which do not go down to inerodable strata, have to be taken. Also, the amount of afflux determines the top level and length of guide banks, if any, and the top levels and sections of flood protection works and approach embankments. A high afflux also means an increase in the area of land liable to submergence. It is, therefore, desirable to keep down the afflux to as low a figure as possible.

3.24. The afflux to bc adopted in design shall correspond to thc design-flood. This may bc calculated from any rational formula. If the area of obstruction is not very large compared to the original

unrestricted area, the following formula of 'Molesworth' will give reasonably good results:—

$$h = \left[\frac{V^2}{58.6} + 0.05\right]\left[\left(\frac{A}{a}\right)^2 - 1\right]$$

Where h = afflux in feet ;

V = Velocity in the unobstructed stream in feet per second ;

A = the unobstructed sectional area of the river in square feet ;

a = the obstructed sectional area of the river in square feet.

If the value of V varies considerably in the unobstructed cross-section of the river as in the case of a river which spills over its banks, V for the purposes of this formula may be taken as the average velocity in the main stream. Correspondingly, the value of A should be determined by dividing the total discharge by V.

In case of readily erodable beds, full afflux as calculated by the above formula may not occur.

3.25. The afflux should be restricted to such a value that a velocity so high as to cause excessive bed scour, is not developed in the stream.

3.26. The effect of afflux on the submergence of the surrounding country should be specially studied. The area of the land which will be submerged depends not only on the magnitude of the afflux, but also on the slope of the countryside, both longitudinal and transverse. Again, the nature and value of the land and other property liable to submergence vary considerably from place to place. Accordingly, in certain cases even considerable submergence of the countryside may be comparatively harmless, while in other cases even a small afflux may cause extensive damage to property. No hard and fast rules on the permissible limit of afflux can, therefore, be laid down beyond the general statement that harmful afflux should be avoided.

Clearance

3.27. Clearance may be defined as the height measured from the free surface of the water, including afflux, at the designed flood level, to a point on the superstructure of the bridge, where the clearance is required to be measured.

3.28. Clearance has to be allowed to suit navigational or anti-obstructional requirements.

3.29. In the case of bridges with approximately rectangular openings the minimum clearance to the soffit of the main beam or

slab should be related to the flood discharge. The following are suggested as suitable minimum clearances for purposes of design:—

Discharge	Vertical clearance
Below 1,000 cusecs	3 feet
1,000 cusecs to 10,000 cusecs	4 ,,
More than 10,000 cusecs but less than 1,00,000 cusecs	5 ,,
1,00,000 cusecs and above	6 ,,

3.30. In the case of smaller bridges, the Committee has recommended a clearance higher than what has been normally allowed in the past. The reason is that the risk of a small clearance being quickly reduced in the event of a discharge higher than the designed figure being experienced is relatively greater in a small bridge than in a large bridge. However, this clearance may be reduced at the discretion of the engineer, where local conditions so require.

3.31. In the case of arch openings it is suggested that the minimum clearance measured to the crown of the arch should normally be as laid down in the following table:—

Arch span	Clearance
Less than 10′ . . .	Rise or 4′ whichever is more.
10′ to 20′ . . .	2/3 rise or 5′ whichever is more.
20′ to 70′ . . .	2/3 rise or 6′ whichever is more.
Above 70′ . . .	2/3 rise.

3.32. No part of the bearings should be at a height of less than 2 feet above the design-flood level inclusive of afflux.

3.33. In the case of rivers the beds of which have a tendency to rise progressively, clearance should be fixed more generously in order to ensure that the bridge decking will not require to be raised too frequently.

Free-Board

3.34. Subject to the protection against wave wash and other local conditions, the free-board for railway embankments should not be less than three feet above the 'foundation design-flood' level plus afflux. This free-board applies to approach embankments to bridges without guide banks. If the bridge is protected by guide banks, this free-board for the approach embankment should be reckoned above the 'foundation design-flood' level at the nose of the upstream guide bank or in the water pocket behind the guide bank whichever is higher. Both these levels will be higher than the level at the bridge.

Training Works

3.35. The object of training is two-fold:—

(i) to guide the river through the waterway provided, with as little obliquity of flow as possible; and

(ii) to keep the river at a safe distance from bridge approaches in order to keep intact the line of communications.

3.36. The most common form of training work, particularly for big rivers flowing in alluvium, still remains the guide bank system the design of which is given in detail in Spring's Technical Paper No. 153 issued by the Railway Board. The Committee recommends that so far as rivers flowing in alluvium are concerned, the training works should continue to be designed on the basic principles enunciated by Spring, modified, if necessary, in the light of model experiments which may be carried out for important bridge works where river training presents problems.

3.37. For rivers in montane and sub-montane stages, the bed slopes are generally very steep and the grade of bed material very heavy so that the bed scour will be very much less than that for a river carrying the same discharge in an alluvial bed. Also the bed scour will be very uneven and hence prevent the river from assuming a definite regime. Such uneven scour may not be suitable for the launching of an apron, a feature on which the success of the usual type of guide bank with apron protection depends. A guide bund on such rivers may not serve effectively either to prevent obliquity of flow through the restricted waterway or to keep the river from attacking the approach bank.

3.38. Again, on account of the steep bed slope and high velocity of flow, a long guide bund will mean a very much higher level of water in the still water pocket behind the bund, as compared to the water level in the main channel. This means a corresponding increase in the top level of the guide bund and much more so of the approach banks, with consequential increases in their sections.

3.39. In such cases, attempt should be made to anchor the head of the guide bund into the side of the gorge or against a fairly permanent high bank, so as to prevent the formation of a still water pocket behind the guide bund and thus to prevent the direct access of the river to the approach banks. The top level of such anchored guide bunds should be given a slope equal to the flood slope so as to ensure a uniform free-board all along the bund. In case it is not possible to anchor the guide bund into high ground, its top should be kept throughout at the level required at the nose.

3.40. Another point of detail on which the design of a guide bund in a submontane reach should differ slightly from that of a guide bund in an alluvial plain, is that the length of the downstream portion of the guide bund should be somewhat longer than that considered suitable for a guide bund in an alluvial plain. The reason is that there is a greater danger of river attack on the approach bank from the channel emerging from the downstream end of the guide bund in the submontane reach than in the alluvium reach of the river.

3.41. The thickness of pitching on the slopes of guide bunds and the thickness of the apron protection should also be heavier than that recommended by Spring for guide bunds in alluvial beds. The apron should not consist of loose boulders or stones, but should be built of large cement concrete blocks, chained together, or of wire-crated boulders or a combination of the two. Here the Committee would like to suggest that the practice of laying the wire-crates longitudinally along the toe of the slopes which has been generally followed in the past, should be carefully reviewed, as it may be preferable to lay wire-crates perpendicularly to the guide bunds.

Protection Works

3.42. The Committee has no great modifications to suggest in the existing practice relating to the design of spurs, groynes, and protective pitchings for approach embankments, except that in the case of approach banks which are, or are likely to be, subject to the parallel flow of water, the question of providing an apron at the toe of the pitching or some other protective measure should be seriously considered. The ideal arrangement would, of course, be to design the lay-out of the bridge and its protection works in such a way that parallel flow is prevented, but if this is not possible and there is a likelihood of the approach banks being attacked, the desirability of providing pitching on the upstream slopes and aprons for suitable lengths on either approach of the bridge should be considered.

3.43. Small bridges and culverts with a waterway of up to about 20 feet should normally be provided with flooring and splayed wing walls to give smooth entry and exit. The downstream curtain wall in such cases should be protected by an apron of a suitable length designed to cater for the maximum scour. If a standing wave or hydraulic jump is expected to form downstream of the bridge, the protection should extend in the form of an apron to a point well beyond the point of formation of the standing wave. The apron should have under it a blanket of inverted filter to prevent the bed sand being sucked out by the pressure differentials at the standing wave.

General

3.44. In approach banks where there is a considerable difference in the levels of water standing against the bank on the upstream and the downstream sides, the bank should be protected against piping. In such cases, the bank should be designed to act as an earthen dam.

3.45. The importance of maintaining the regime of the channel both upstream and downstream of the bridge—even in the case of comparatively small streams—cannot be over-emphasised. The course of the stream should be periodically surveyed for an adequate distance both upstream and downstream and remedial measures, including removal of vegetation and other undesirable obstructions, taken to ensure normal and smooth flow through the bridge, as far as possible.

3.46. While it will be desirable to design new bridges on the standards laid down in this report, it does not follow that of the thousands of existing bridges those that do not satisfy one or more of these standards need necessarily be enlarged or reconstructed. A careful study of those bridges should be made and ways and means devised to ensure the safety of these bridges by providing suitable bed protection in cases where foundations are inadequate in depth and in other cases by suitable protection works, improvement in channel regime and approach conditions, increase in clearance, etc.

PART IV

ORGANISATION FOR IMPLEMENTING THE SHORT-TERM AND THE LONG-TERM PLANS AND ITS FUNCTIONS

PART IV

ORGANISATION FOR IMPLEMENTING THE SHORT-TERM AND THE LONG-TERM PLANS AND ITS FUNCTIONS

Short-Term Plan

4.01. The short-term plan will deal essentially with:—

(a) the collection and analysis of large volume of hydrological, meteorological and topographical data which already exists;

(b) the preparation and execution of a comprehensive plan for the collection and analysis of further data, the collection of which must extend over at least two monsoon periods;

(c) the observation of actual discharges at a large number of representative bridges, covering the whole country, the computation of the maximum discharges for the highest flood levels recorded on the bridges and the correlation of these discharges with the size, slope and nature of catchments, rainfall pattern etc.;

(d) the fixation of values of 'C' in an empirical formula or formulae to be evolved for the determination of the design-flood or the preparation of graphs and charts showing the correlation between discharge, catchment area and the rainfall pattern; and

(e) the study of design practices of other advanced countries.

The results of these studies will be required for application, pending development of better and improved methods of determining flood peaks under the long-term plan.

4.02. The studies made during the short-term plan will also be useful in the investigations under the long-term plan.

4.03. The first task in the short-term plan is to assemble and present in a readily workable form all the relevant data for the various bridges in the different regions of the country. Thereafter, these data should be analysed in a central place.

4.04. As bridges over streams having catchments of small and medium sizes are the ones which cause most of the problems, a comprehensive programme of hydrological, meteorological and topo-

graphical investigations should be drawn up to cover representative catchments of various types and sizes. Arrangements should be made for observation of gauges and discharges at regular and brief intervals of time depending on the catchments. Pending installation of a network of intensity rain-gauges and automatic stream-gauges, arrangements should be made for hourly record of rainfall and stream-gauges at selected places. These will help in establishing correct rainfall-run-off relationship, a matter which is very important in estimating coefficients of flood run-off and which at present is subject to considerable speculation. Such data will be of value, even in the interim period, to evaluate floods from typical small catchments for any design intensity rainfall.

4.05. Another important work that can be taken up during the short-term plan is a review of the 'Problem' bridges. These studies will help in undertaking improvements to existing bridges on a phased basis, as the situation warrants. The Railway Board have already set up an organisation on each Railway for this purpose. This organisation should be continued and suitably reinforced as required.

4.06. Simultaneously, a cell should be established in the Railway Board under an eminent Bridge Engineer, not below the rank of a Chief Engineer, to collect, systematise and analyse all the voluminous data received from the various Railways and other organisations and establish values of coefficient in an empirical formula to be evolved as detailed in paragraph 2.14. This Officer will also provide necessary liaison between the Railway Board, Central Water & Power Commission, Indian Meteorological Department and the Roads Wing of the Ministry of Transport.

Long-Term Plan

4.07. The long-term plan will include:—

(a) the preparation of intensity-frequency charts of rainfall;

(b) the analysis of all past and present storms;

(c) the establishment of unit hydrographs for representative catchments of different regions;

(d) the study of the behaviour of the existing bridges (including other hydraulic structures), and the assessment of the adequacy of current theory and practice; and

(e) the task of bringing up-to-date information and knowledge contained in the classics on this subject written in India by Spring, Kennedy, Lacey, Khosla etc.

The programme of these studies would naturally be adjusted in the light of subsequent knowledge on the subject as it becomes available. It is becoming increasingly clear that one of the biggest stumbling blocks in the preparation of proper plans and designs for Railways, Highways, Irrigation & Power or other engineering structures, is the inadequacy of hydrological data and their interpretation for application to various fields.

4.08. One of the fundamental requisites is the rapid installation of a network of self-recording rain-gauges. It is understood that almost all the components of a self-recording rain-gauge are being made in India, but for a few parts which are still being imported from abroad. The progress in the manufacture and erection of self-recording rain-gauges has been held up due to difficulty in obtaining the requisite foreign exchange for such parts. The Committee recommends that the necessary foreign exchange should be allotted immediately to enable the installation work to be undertaken at once on a priority basis, and essential requirements completed within a period of three years, so that sufficient data become available for detailed analysis. A beginning should, however, be made with the data that are already available from the self-recording rain-gauges in the country.

4.09. The installation of rain-gauges should be done after careful consideration of the location of the existing self-recording rain-gauges, the catchments which have already been taken up for discharge observation and those which will be taken up hereafter, keeping in view the future development of the Railways. Equally important is the installation of automatic stream-gauges in the various representative streams in catchments of small and medium sizes throughout the country and the collection and analysis of the data so obtained. The proposals for additional self-recording rain-gauges and stream-gauges should be drawn up by a Committee, consisting of representatives of the Railway Board, Indian Meteorological Department, Central Water & Power Commission and Roads Wing of the Ministry of Transport, to be set up for the purpose under the Chairmanship of the 'Special Bridge Engineer', after taking into account the network of self-recording rain-gauges already proposed by the Indian Meteorological Department and the Central Water & Power Commission during the Second Five-Year Plan period.

4.10. Another work that must be carried out as a part of the long-term plan is the study of storms for the whole of India. This study should cover all past recorded storms. This will be of valuable aid in fixing design-flood figures for catchments. This study is equally essential for purposes of water, power and allied development plans of the country.

4.11. It is essential that an organisation adequate to deal with the voluminous work mentioned above, should be set up on a permanent basis. This organisation will have wings in the Railway Board, Central Water & Power Commission, Indian Meteorological Department and the Roads Wing of the Ministry of Transport. In addition, there must be provision for co-ordination of work done in all these wings as well as other organisations in the States dealing with the subject.

4.12. The wing in the Railway Board should constitute a Directorate of Bridge Engineering. The functions of this Directorate will be:—

(i) to collect and analyse all data received from the Bridge Reviewing Cells already functioning on each Railway;

(ii) to arrange observation of discharges at selected railway bridges and hourly gauge record at these bridges during floods; and

(iii) to provide basic material for the design of railway bridges in the various regions of the country on the basis of data collected and analysed in this Directorate and in the wings proposed to be set up in the Central Water & Power Commission, Indian Meteorological Department and the Roads Wing of the Ministry of Transport.

4.13. The wing in the Central Water & Power Commission should constitute a separate cell to perform the following functions in co-ordination with the Indian Meteorological Department:—

(i) to derive rainfall-runoff relationships for different regions over the country;

(ii) to derive unit hydrographs and carry out routine studies;

(iii) to carry out analysis of specific storms for special requirements; and

(iv) to determine maximum flood discharges of different basins and sub-basins in the country utilising the storm depth-duration-area and other data worked out by the corresponding cell in the Indian Meteorological Department.

4.14. The wing in the Indian Meteorological Department will constitute a separate cell to perform the following functions in co-ordination with the Central Water & Power Commission:—

(i) to divide the country into meteorological regions for purposes of storm analysis;

(ii) to carry out a systematic analysis of past storms in different parts of the country to derive the maximum depth-duration-area data, and to study the characteristics of the meteorological situations responsible for these storms;

(iii) to install and maintain self-recording rain-gauges;

(iv) to collect the data of all self-recording rain-gauges (already existing and newly set up) and scrutinise and process them; and

(v) to study the duration and intensity of rainfall with return periods using the data in (iv) above.

4.15. The wing in the Roads Organisation will constitute a separate cell to perform the following functions:—

(i) to collect information about the behaviour of road bridges in respect of floods, scour, afflux etc. from the State Public Works Department;

(ii) to arrange for further information to be collected to fill up gaps in the existing information; and

(iii) to analyse such information and put it in an usable form.

4.16. In order that the work of these four wings be carried out to the best advantage, there should be a Co-ordinating & Planning Committee consisting of the heads of these wings with Director, Bridge Engineering, Railway Board, as Chairman.

4.17. The functions of this Co-ordinating & Planning Committee will be:—

(i) to plan and allocate work to the various wings;

(ii) to review and assess the work done by these wings; and

(iii) to approve and arrange publication of the studies.

PART V

MEASURES TO ENSURE SAFETY OF RAILWAY BRIDGES AGAINST FAILURE OF VARIOUS 'RAILWAY AFFECTING' WORKS.

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MEASURES TO ENSURE SAFETY OF RAILWAY BRIDGES AGAINST FAILURE OF VARIOUS 'RAILWAY AFFECTING' WORKS

Third Term of Reference

5.01. 'Railway affecting' works may generally be defined as such works, the failure of which is likely to cause serious damage to a railway embankment or a bridge. These works may be broadly classified as follows:—

(i) Irrigation and water supply tanks or reservoirs;

(ii) Canals in embankment and river embankments;

(iii) Road embankments with inadequate waterway for drainage situated upstream of the railway line;

(iv) Temporary channels cut for irrigation or other purposes from beds of active rivers; and

(v) Other works or operations which might alter or impede the natural course of flood flow or cause an increase in the volume of such flow. These may be new irrigation projects, new townships, new forest belts, large scale deforestation etc.

5.02. There have been a number of instances where failure of 'Railway affecting' works has led to breaches in the railway embankments and in some cases to train accidents.

5.03. 'Railway affecting' works are owned and controlled by a multiplicity of agencies, such as Public Works, Irrigation and Revenue departments of the State Governments, private organisations and individual owners etc. In a number of cases, no statutory obligation has been placed on the owners for adequate maintenance of such works the failure of which might adversely affect the safety of railway lines situated downstream. It is, therefore, necessary to review the whole question of responsibility for and maintenance of such works and evolve a unified procedure, which would ensure against failure of such works and thus secure safety of the railway track and the travelling public.

State Committee of Engineers

5.04. The Committee is pleased to note that this subject was discussed at a Conference held on 5th June, 1957 between the Union Minister for Railways and Chief Ministers of the States. As a result of this Conference, a Committee of Engineers consisting of Senior Officers from the Railways, Public Works, Irrigation, Forest and Local Self-Government Departments of the State concerned, has been set up in each State. These Committees have been charged with the responsibility of maintaining up-to-date lists of 'Railway affecting' works and bringing about co-ordination between the Railways and the State authorities in respect of policies and programmes of proper upkeep of such works, whether belonging to the State or private agencies.

5.05. The functions of these Committees of Engineers are laid down in para 4 of Ministry of Railways (Railway Board) letter No. 57/WII/CMT/20 dated 23rd June, 1957 (Appendix B) and are as follows:—

"(a) Exchange of information about schemes envisaged by any one department and likely to affect the working or safety of assets of another department and consequential safeguards to be adopted.

(b) Keeping up-to-date the list of railway affecting works, etc., naming the officials responsible for joint inspection of each such work immediately after monsoons and, if possible, also in advance of monsoons; and watching that the department responsible for proper maintenance of such works promptly carries out the necessary repairs.

(c) Evolving a procedure for:—

(i) obtaining and broadcasting, by departments concerned, warnings or forecasts of heavy rains, floods, storms, etc., as well as the actual heavy rainfall recorded and expected floods downstream, to the officers concerned in the various Departments; and

(ii) inducing public co-operation in promptly conveying to the department concerned any unusual occurrence, *e.g.*, breaches of tanks etc.;

(d) Assessing whether waterways, protection works, etc., provided by any department in an area severely affected by floods have proved to be inadequate and improvements needed for future;

(e) Co-ordination of related schemes of the various departments represented."

5.06. It would thus be seen that these Committees are principally concerned with the safety aspect of Railway working and also the safety of other public works affected by railway track, bridges, etc.

Irrigation and Water Supply Tanks, Canals etc.

5.07. All tanks in the catchment of a stream crossing a railway line are not necessarily 'Railway affecting'. Conditions will differ from region to region. Each State Committee of Engineers should lay down guiding principles, for the classification of the 'Railway affecting' tanks within its jurisdiction, which may be added to or modified as a result of further experience.

5.08. To ensure the safety of the travelling public, it is most necessary that the 'Railway affecting' works be maintained properly, and thus be secured against failure. This will require examining the adequacy of designs of each bund and surplus works etc. arranging periodical inspections and any defects or deficiencies attended to.

5.09. It is recommended that:—

(a) the State Committees of Engineers should prepare a list of and notify all 'Railway affecting' works;

(b) the State Committees of Engineers should arrange for submission of annual report of inspection (emergency reports where necessary) and of any works that may have been carried out to make up deficiencies in any of the railway affecting tanks and appurtenance;

(c) the State Committees of Engineers should arrange for a system of watch and the issue of warnings of apprehended and actual breaches of tanks and also devise suitable warning signals in the event of a breach occurring or threatened; and

(d) the State Government concerned should be entrusted with the responsibility for checking up and ensuring the maintenance of all 'Railway affecting' works, their watch, and the issue of warnings if a breach occurs or is apprehended, and taking suitable action through their appropriate departments.

5.10. It is further recommended that the adequacy of waterways and other features of design of railway bridges over such streams as have 'Railway affecting' works in their catchment, should be

examined and those which prove to be inadequate, should be suitably strengthened or reconstructed under advice of the concerned State Committee of Engineers.

Temporary channels, cut for Irrigation and other purposes from beds of active rivers

5.11. Channels are often dug by villagers from beds of active rivers for purposes of irrigation, generally without permission and often without the knowledge of the Irrigation or Railway authorities concerned. It is recommended that the State Irrigation Department should be charged with the responsibility of according approval to the construction of any such channels, including the stipulation that their intakes shall be closed off in good time before the commencement of the monsoon. The Irrigation Department should also have the authority to take action against unauthorised excavation of such channels.

Construction of 'Railway Affecting' Works

5.12. It is recommended that for the construction of any work, which is likely to become 'Railway affecting', it should be made obligatory for the party concerned to obtain formal approval of the Railway concerned and to give an undertaking that it would abide by the conditions laid down by that Railway regarding issue of timely warnings to enable the Railway authorities to take adequate steps for the protection of the Railway line, including arrangements for special patrolling.

Proposed Statutory and other provisions

5.13. In order that the directions in respect of maintenance and/or construction of 'Railway affecting' works be comprehensive and the procedure unified for all the States, it is recommended that a Manual of Instructions be prepared on an all-India basis. Each State should, in addition, have a list of 'Railway affecting' works (which should be kept up-to-date), indicating their design features and the extent to which each one is likely to be railway affecting, and also evolve a system of watch and warnings and instructions for emergency action.

5.14. It is further recommended that the essential requirements of safety as set forth in the Manual of Instructions referred to above, may be incorporated in a Central statute either as an amendment to the Indian Railway Act or as a separate Act, which in the interest of public safety will be binding on the State Governments and the

public. This statute should also deal with the financial implications of the various recommendations and the apportionment of costs and responsibility.

5.15. Although not within the terms of reference, the Committee would like to draw attention to paragraph 5·05(a) and to suggest that if any work proposed by one Department is likely to affect the works of other Departments, prior concurrence of the latter should be taken.

PART VI
CONCLUSIONS
AND
SUMMARY OF RECOMMENDATIONS

PART VI

CONCLUSIONS AND SUMMARY OF RECOMMENDATIONS

General Conclusions

6.01. There are many thousands of bridges in the country, some of them over a hundred years old. Most of these bridges have stood the test of time and bear testimony to the intuition, skill and sound judgment of the engineers in India, who did pioneer work in this field. Major advances in hydraulic engineering, model experiments, science of hydrology and organised collection of hydraulic and, in some essential respects, of meteorological data, are of recent origin and mainly date back to two to four decades. Despite the handicap of the lack of essential data and the later advances in knowledge on the subject, which were naturally not available to them, these pioneers succeeded in constructing stable major structures. There have been occasional failures. Studies of these as well as of failures in other parts of the world and of the thousands of structures that have stood firm, have provided the basis for and helped in the evolution of modern hydraulics and the science of bridge engineering, the ultimate aim of which is to secure stability of structures at minimum first cost and subsequent maintenance charges.

6.02. In assessing the damage to a bridge and deciding on its repairs, of primary importance will be a careful and objective appraisal of the cause or causes of damage. Damage may occur due to inadequate waterway, insufficient depth of foundations, unfavourable approach or exit conditions, inadequate or faulty protection works, weakness in approach banks, unprecedented or unpredictable rainfall, swelling of flood discharge from breaches in tanks, canals etc. Damage may also occur through overbridging or providing excess waterway which may result in dangerous meanders presenting hazards of parallel flow and concentration of discharge at critical points in the structure. Overbridging will also be unnecessarily wasteful in expenditure. A classic example of such overbridging is the Alexandra Bridge (1870 to 1875) over the Chenab at Wazirabad (now in Pakistan) which had a khadir of 4 miles width of which close on two miles was bridged by 64 spans of 142 feet centres. The bridge was later cut down to 28 spans by closing 16 spans on the north (1888) and 20 spans on the south (1890). On further investigations based on the knowledge gained about guide bank system of training, the waterway was further reduced to 17 spans in the year 1927.

6.03. An incorrect appraisal of the damage to a bridge or causes leading to it, may result in overbridging or incorrect design of additions, alterations and reconstruction works and besides resulting in wasteful expenditure, may even be harmful on structural or hydraulic grounds. Panicky action and complacence would be equally out of place in dealing with damage to or repair of important structures like railway bridges.

6.04. The Committee wish to emphasise that while bridges must be made safe for the 'foundation design-discharge', it will be uneconomical to cater for a larger discharge which may occur during the life time of a bridge due to variety of reasons, such as unusual cloud bursts, bursting of a tank or a dam etc.

6.05. The basic factor in the design of a bridge is the assessment of discharge through the structure. The discharge, however, is affected by so many variables that it is extremely difficult to arrive at a reasonably correct value without accurate and long-term meteorological and hydrological data. The correlation between rainfall and discharge for varying terrains (size, shape, nature of soil, extent of storage capacity etc.) and climates (intensity, duration and sequence of rainfall, its distribution over the catchment area, prevailing winds etc.) cannot, therefore, be scientifically established. As there are very few automatic rain-gauges and stream-gauges in the country, it is imperative to install these as soon as possible. This handicap can be overcome only by giving the earliest attention to the need for the collection of continuous data, both meteorological and hydrological, all over the country in a systematic and sustained manner. A start in this direction has since been made. Recommendations for further work are contained in Part IV. Even so, it will take a decade or two before adequate data become available. The Committee have, therefore, suggested a short-term plan for early application and a long-term plan for providing a better and improved approach.

6.06. A very large number of the bridges are old and were constructed on data then available and on principles then known. Some of these bridges may need modifications to bring them up to the present-day standards. One of the common weaknesses lies in the inadequacy of bank protection works against the river action during high floods. There can also be cases where depth of scour and afflux in relation to the highest flood discharge has not been fully taken care of. It is necessary to make a complete survey of such bridges, their design and construction features and history of

performance, so as to have a correct appraisal of their stability in the light of up-to-date knowledge of theory and practice and also to determine thereby the most economical remedial measures.

6.07. A bridge with its approaches designed on sound lines based on well-established practice, needs to be maintained in good order for efficient performance. Once an obstruction in the shape of a bridge and its approach bank is placed across a natural stream, the latter has to adapt itself to the new conditions created in its path. Depending on the extent of obstruction, the stream may scour the bed or erode its bank on the upstream or deposit silt, form shoals or sand bars resulting in growth of bushes, shrubs and even trees. It is suggested that at every flood opening, the course of the stream should be periodically surveyed for an adequate distance both upstream and downstream and remedial measures taken where the flow through the bridge is not straight and smooth.

6.08. As explained in paragraph 2.15, it has not been possible for the Committee to evolve a new formula for general application or to prescribe constants in the existing empirical formulae for determining the design-discharge. This work has, of necessity, to be left to the 'Special Bridge Engineer' to complete.

Second Committee

6.09. It is recommended that a similar High-level Committee of Engineers be set up in due course after the 'Special Bridge Engineer' has submitted his report.

SUMMARY OF RECOMMENDATIONS

	Paragraph No.
6.10. This report deals mainly with catchments of small and medium sizes which are the ones presenting the greatest problems. The principles enunciated are generally also applicable to catchments of larger sizes.	1.09
6.11. The recommendations made in the report are in respect of bridges built to 'Main Line' standards.	1.10
Determination of maximum discharge for the design of waterway of Bridges	
6.12. The waterway of bridges should be designed to cater for the maximum recorded flood when the data available extends over a period of not less than 50 years, or for a 50-year flood when data available are for a lesser period.	2.09

Paragraph No.

6.13. Foundations and protection works should, however, be designed for a larger flood, named as 'foundation design-flood'. 2.10

6.14. For better results, collection of requisite data should be started immediately in accordance with a systematic plan to cover the entire country. As such, the evolution of the revised approach will have to be considered as a long-term measure, but a short-term plan based on available data or data that can be readily collected is proposed with a view to improving the present approach, as soon as possible. In the meantime, however, the established practices as obtaining in different regions have to continue. 2.06

6.15. The Committee have suggested two plans as under:—

I. Short-term plan

(a) it is recommended that only one simple formula applicable, if possible, to the whole India should be evolved, with the range in the value of the coefficient reduced to the minimum possible. 2.14

(b) India should be divided into various regions and sub-regions of similar hydro-meteorological conditions and the value of coefficient worked out for different slopes and sizes of the catchments for these regions. 2.16

(c) A practical approach for the determination of the value of coefficient would be to observe actual flood discharges at a large number of representative bridges covering the whole country and then to correlate these discharges with the size, slope and nature of catchments, rainfall pattern etc. 2.17

(d) The Bridge Reviewing Cells already set up on each Railway should continue. 4.05

Paragraph No.

(e) A central cell should be established under an eminent Bridge Engineer in the Railway Board for:— 4.06

(i) the collection and analysis of a large volume of hydrological, meteorological and topographical data which already exists; 4.01

(ii) the preparation and execution of a comprehensive plan for the collection and analysis of further data for at least two monsoon periods;

(iii) the observation of actual discharges at a large number of representative bridges;

(iv) the fixation of value of coefficient in an empirical formula or formulae to be evolved for the determination of the design-flood or the preparation of graphs and charts showing the correlation between discharge, catchment area and the rainfall pattern; and

(v) the study of design practices of other advanced countries.

The results of these studies will be required for application, pending development of better and improved methods under the long-term plan.

II. Long-term plan

The Long-term plan will include:—

(a) the preparation of intensity-frequency charts of rainfall;

(b) the analysis of all past and present storms; 4.07

(c) the establishment of unit hydrographs for representative catchments of different regions;

(d) the study of the behaviour of the existing bridges (including other hydraulic structures) and the assessment of the adequacy of current theory and practice; and

(e) the task of bringing up-to-date the information and knowledge contained in the classics on this subject

Paragraph No.

The programme of these studies would naturally be adjusted in the light of the subsequent knowledge on the subject. 4.07

6.16. One of the fundamental requisites for the purpose would be the rapid installation of a network of self-recording rain-gauges and stream-gauges, essential requirements being completed within three years. Necessary foreign exchange required in this connection should be allotted immediately. 4.08

6.17. The proposal for additional self-recording rain-gauges and stream-gauges should be drawn up by a Committee. 4.09

6.18. An organisation adequate to deal with the voluminous work required should be set up on a permanent basis, with wings in the Railway Board, Central Water & Power Commission, Indian Meteorological Department and the Roads Wing of the Ministry of Transport. 4.11 to 4.15

6.19. There should also be a Co-ordinating & Planning Committee for planning and allocating the work and later reviewing and approving for publication the studies of the various wings. 4.16

6.20. The observed data where available should be the main basis for the determination of discharge. Empirical formulae should be used only as a guide. 2.27

Determination of bed scour for the design of Foundations and Training Works, the extent of Afflux and the minimum Free-Board for Bridges and determination of waterway required.

6.21. There appears to be need for further investigations and research on river regimes, guide banks and protective works, in order to be able to assess the adequacy of existing theory and current practice and to suggest modifications where called for. 3.01

6.22. The design practice in respect of hydraulic structures varies considerably in different engineering organisations and even in similar organisations in different States, mainly because of a lack of co-ordination in respect of interpretation of different

Paragraph No.

hydraulic theories and the assessment of the behaviour of existing structures in the various regions. The Committee has attempted to interpret these theories on the basis of sound practice which has stood the test of time, to focus attention on fundamentals and to evolve uniformity of practice. The correct application of these in actual practice will, however, largely depend on the judgment of the engineer responsible for the design on the basis of his mature experience. 3.03

Design of waterway

6.23. The design of waterway of a bridge is a problem which has two main considerations, namely, hydraulic and economic. A correct balance between these two opposing considerations has to be struck, which will largely be a matter of judgment based on experience. However, some broad principles for determining the correct balance have been laid down. 3.04 3.05 3.06 to 3.11

Depth of Scour

6.24. The pier foundations should be taken to twice the depth of normal scour plus a further depth for grip. It is recommended that the foundations be taken to a depth not less than 1.33D′ (D′ is twice the normal depth of scour) below the 'foundation design-flood' level for all bridges and further research carried out. 3.19

6.25. Records of depth of scour which exist for a large number of bridges and barrages on the major rivers should be centrally collected and analysed. 3.20

6.26. Investigations should also be undertaken to establish relationship between scour depth and flood discharge in gravel and boulder beds and in coherent materials. 3.15

Afflux

6.27. No hard and fast rules on the permissible limit of afflux can be laid down beyond the general statement that harmful afflux should be avoided. 3.26

Clearance

6.28. A higher clearance has been recommended in case of smaller bridges than what has been normally allowed in the past. 3.30

Paragraph No.

Free-board

6.29. The free-board for railway embankments should not be less than 3 feet above the 'foundation design-flood' level plus afflux. 3.34

Training Works

6.30. For rivers flowing in alluvium, the training works should continue to be designed on the basic principles enunciated by Spring, modified, if necessary, in the light of model experiments which may be carried out for important bridge works where river training presents problems. 3.36

6.31. For rivers in montane and sub-montane stages,

(a) a guide bund of the type adopted in alluvium may not serve effectively; 3.37

(b) the length of the downstream portion of the guide bund should be somewhat longer than that considered suitable for a guide bund in alluvial bed; 3.40

(c) the thickness of pitching on the slopes of guide bunds and the thickness of the apron protection should also be heavier than that recommended by Spring for guide bunds in alluvial beds; and 3.41

(d) the apron should not consist of loose boulders, but should be built of large cement concrete blocks chained together or of wire-crated boulders or a combination of the two. The practice of laying wire-crates along the toe of the slopes which has been generally followed in the past, should be carefully reviewed, as it may be preferable to lay wire-crates perpendicularly to the guide bunds. 3.41

Protection Works

6.32. No great modifications have been suggested in the existing practice relating to the design of spurs, groynes, and protective pitchings for approach embankments, except that in the case of approach banks which are, or are likely to be, subject to the parallel flow of water, the question of providing an apron at the toe of the pitching or some other alternative protective measure should be seriously considered. 3.42

Paragraph No.

6.33. Small bridges should normally be provided with flooring and splayed wing walls. The downstream curtain wall should be protected by an apron designed for the maximum scour. 3.43

6.34. If a standing wave or hydraulic jump is expected, the apron should have under it a blanket of inverted filter to prevent the bed sand being sucked out by the pressure differentials. 3.43

General

6.35. The course of the stream should be periodically surveyed and, if necessary, measures taken to ensure normal and smooth flow, as far as possible.

6.36. If an existing bridge does not satisfy one or more of the standards recommended in the report it need not necessarily be enlarged or reconstructed. A careful study of such bridges should be made and ways and means devised to ensure the safety of these bridges by providing suitable bed protection in cases where foundations are inadequate in depth and in other cases by suitable protection works. 3.46

Measures to ensure safety of railway bridges against failure of various 'Railway Affecting' works

6.37. There have been a number of instances where failure of 'Railway affecting' works has led to breaches in railway embankments and in some cases to train accidents. The whole question of responsibility for and maintenance of such works has to be reviewed and a unified procedure evolved. 5.02 5.03

6.38. It is recommended that:—

(a) The State Committee of Engineers should prepare a list of and notify all 'Railway affecting' works; and arrange for submission of annual reports of inspection, system of watch and the issue of warnings of apprehended and actual breaches of tanks. 5.09

(b) The State Governments should be entrusted with the responsibility for checking up and ensuring the maintenance of all 'Railway affecting' works, their watch and issue of warnings. 5.09

Paragraph No.

(c) The State Irrigation Departments should have the authority to take action against unauthorised excavation of channels from beds of active rivers. 5.11

(d) It should be obligatory for the party constructing a work which is likely to become 'Railway affecting' to obtain prior approval of the Railway concerned. 5.12

(e) In order that the directions in respect of maintenance and construction of 'Railway affecting' works be comprehensive and unified for all States, a Manual of Instructions should be prepared on an all-India basis, and the essential requirements of safety, as set forth in this Manual, incorporated in a central statute either as **an** amendment to the Indian Railway Act **or** as a separate Act. 5.13 5.14

30.9.59
(A.N.Khosla, M.P.)
Chairman

(R.E.Aserappa)
Member

30.9.59
(N.K.Roy)
Member

(H.P.Sinha)
Member

(S.L.Bazaz)
Member

(P.R.Ahuja)
Member

(B.B.Varma)
Member

(P.C.Khanna)
Member

(M.R.Venkataram)
Member

(S.D.Bamjee)
Member

30.9.59
(H.K.L.Sethi)
Member

(D.R.Kohli)
Member

(R.D.Dhir)
Member

(S. Basu)
Member

(N.K.Mehra)
Secretary

APPENDIX 'A'

GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS
(Railway Board)

No. 57/W-II/CMT/13 New Delhi, dated 7th July 1957.

To

The Chief Secretaries to the Government of—

Andhra Pradesh, Hyderabad;
Assam, Shillong;
Bihar, Patna;
Bombay, Bombay;
Kerala, Trivandrum;
Madhya Pradesh, Bhopal;
Madras, Madras;
Mysore, Bangalore;
Orissa, Bhuvaneshwar (Cuttack);
Punjab, Chandigarh;
Rajasthan, Jaipur;
Uttar Pradesh, Lucknow;
West Bengal, Calcutta.

The Secretary to the Lt. Governor, Himachal Pradesh, Simla.

Subject:—Questionnaire on estimating maximum flood discharges, Hydrological and Meteorological data

Sir,

The Ministry of Railways (Railway Board) have set up a Committee of Engineers under the Chairmanship of Dr. A. N. Khosla, Vice-Chancellor, University of Roorkee, to review the various methods of estimating maximum flood discharges from catchments for the purpose of working out the waterways of bridges and fixing the design of their foundation works and the extent of protection

works needed. The Committee will also make an attempt to rationalise the flood discharge formulae in the light of knowledge acquired about rainfall intensities and run out and the experience gained from the behaviour of the existing bridges.

2. The Committee are naturally keen that all the relevant data available with all the authorities in the country is collected and examined and analysed in detail so that the conclusions arrived at are based on and take cognisance of all the information available. The enclosed Questionnaire has been drawn up by the Committee for collecting the information available with the various Departments of the States and with other authorities. The Committee desire that you may forward copies of the Questionnaire to the technical Heads of the State Departments concerned *e.g.*, Irrigation Department and Public Works Department, B&R. with a request that answers to the Questionnaire may be forwarded directly to the undersigned by 10th August 1957. It may so happen that all the information required to frame answers to certain questions cannot be collected by the said date and in that case the remaining information may be forwarded not later than 10th September 1957.

Yours faithfully,

(Sd.) D. N. CHOPRA.

for Secretary, Railway Board.

Enc.: One Questionnaire (with 5 spare copies).

No. 57/W-II/CMT/13. New Delhi, dated 7th July 1957.

Copy with a copy of the Questionnaire is forwarded to:

1. The General Managers, All Indian Railways.
2. The Chairman, Damodar Valley Corporation, Anderson Building, Calcutta.
3. The Chief Engineers Eastern Command, Lucknow, Western Command, Simla and Southern Command, Poona.
4. The Chief Engineer, Hirakud Project, Hirakud.
5. The Chief Engineer, Kosi Project, Kosi.
6. The General Manager, Bhakra Dam Project, Nangal, Punjab.

They are also requested that comprehensive answers to the Questionnaire may kindly be sent to the undersigned by the dates mentioned in the letter.

(Sd.) D. N. CHOPRA.

for Secretary, Railway Board.

Enc.: One Questionnaire (with 2 spare copies).

COMMITTEE OF ENGINEERS

QUESTIONNAIRE

1. Supply a 1" = 16 miles index map of the State showing the following:—

(a) River systems;

(b) Major Roads and Railway Bridges;

(c) Location of Rain Gauges;

(d) Location of river gauging stations; and

(e) Areas subject to storms and cyclonic weather.

2. At what period of the year (month) do you experience the high floods and what are their approximate durations?

3A. Give history of storms, cyclones or other cases of heavy rainfall, mentioning clearly—

(a) Name of the place or locality;

(b) Brief particulars of the occurrence; and

(c) Record of rainfall thereof showing:—

(i) Area covered by the storm,

(ii) Its duration in hours,

(iii) Maximum daily and hourly intensity of rainfall during the storm.

B. Give records taken during the storm at bridges, if any, with the following particulars:—

(i) Details of the bridge;

(ii) Area of its catchment with brief particulars of its shape, nature and slope at the crossing; and

(iii) Recorded maximum discharge during the storm, approximate if not calculated.

4. What are the formulae in use for the determination of the maximum discharge for the design of bridge openings? For em-

pirical formulae, the constants may be stated in each case. If different formulae are adopted for different regions of the State, this may be indicated clearly.

5. What is the experience of the State/Railway about the formulae used? Have the discharges noted at the bridges, after constructions, agreed with the discharge adopted in the design?

6. Are there cases when the discharge noted at the bridges varied greatly from the designed discharge?

Brief particulars of such cases, as many as possible, may please be given, dealing with the following—

(a) Particulars of the bridge;

(b) Area of its catchment, its shape, nature and slope;

(c) Bed and flood slope at the bridge;

(d) Formula used for determination of the design discharge;

(e) Design discharge;

(f) Discharges actually recorded during high floods;

(g) Velocities at high flood, estimated if not recorded; and

(h) Daily rainfall for preceding days leading to the flood, with maximum hourly intensities if recorded or estimated.

7. How do you calculate the deepest scour and depth of foundation required in the design of the bridge and its protective works? A few typical calculations may please be enclosed.

8. Are there any statutory provisions in your State for safeguarding the Railway line against breaches due to the failure of Railway affecting works such as dams, canals, storage tanks, reservoirs etc.? If so, the details of such provisions may please be furnished.

9. If there are no statutory provisions referred to in item 8 above, please suggest measures that should be undertaken in ensuring the safety of Railway line.

10. How are affluxes calculated for the bridges?

11. What are maximum affluxes permitted in openings of different kinds and in different areas?

12. What are the principles on which the free board between the designed H.F.L. and the bottom of girders is calculated?

PROBLEM BRIDGES

Definition—Problem bridges are those which have given trouble, or are likely to give trouble, owing to inadequate waterways, inadequate protection works or other causes.

13. Give a list of problem bridges (and in respect of each one of them give the information covered by Question Nos. 14 to 21 below).

14. Give site plan showing the lie of the channel for sufficient distances upstream and downstream and also cross sections at the site of bridge as well as upstream and downstream of the bridge.

15. Give the H.F.Ls. noted, along with dates, and also give flood slope and flood velocity if measured at site, alternatively give estimated figures, mentioning this fact.

16. State the assumptions made in the design of water-way and depth of foundations.

17. Give statement of affluxes observed and the corresponding gauges and discharges, with dates.

18. Is the full discharge going through the bridge? If not what is the amount of valley storage, or spill, immediately above the bridge.

19. Give a statement of depth observed during high floods. What is the nature of bed material and what is the silt factor applicable to it?

20. Has there been any addition to, or curtailment of, the waterway since the construction of the bridge?

21. Describe any existing protection works in the shape of guide bunds or marginal banks and/or protection on approach embankments, with full particulars of extent of pitching on slope and apron. Give sketches showing the position of these works and their cross sections.

22. Give a note on the approach condition of the river, detailing the location of any shoals, vegetation growth and deep channels.

APPENDIX 'B'

GOVERNMENT OF INDIA

MINISTRY OF RAILWAYS

(Railway Board)

No. 57/W-II/CMT/20. New Delhi, dated 23rd June, 1957.

To

The Chief Secretaries to the Government of—

Andhra Pradesh, Hyderabad;
Assam, Shillong;
Bihar, Patna;
Bombay, Bombay;
Kerala, Trivandrum;
Madhya Pradesh, Bhopal,
Madras, Madras;
Mysore, Bangalore;
Orissa, Bhuvaneshwar (Cuttack);
Punjab, Chandigarh;
Rajasthan, Jaipur;
Uttar Pradesh, Lucknow;
West Bengal, Calcutta.

The Secretary to the Lt. Governor, Himachal Pradesh, Simla.

Subject:—Appointment of a Committee of Engineers, P.W.D., Irrigation and Railways, etc., for Railway affecting and other Public Works.

Sir,

With reference to the meeting between the Chief Ministers of States and the Minister for Railways held in New Delhi on 5th June, 1957, two copies of the directive No. 57/W-II/CMT/20 dated 22nd June, 1957, to the General Managers of all Indian Government Railways, are forwarded with the request that the Committee of Engineers may please be set up in your State as early as possible. Two copies of the minutes of the meeting have been forwarded to you separately.

Yours faithfully,
(Sd.) H. D. AWASTY.
for Secretary, Railway Board.

DA: Two copies.

GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS
(Railway Board)

No. 57|W-II|CMT|20 New Delhi, dated 22nd|23rd June, 1957.

To

The General Managers,
All Indian Railways.

Subject:—Appointment of a Committee of Engineers P.W.D., Irrigation and Railways, etc., for Railway affecting and other Public Works.

The above subject was discussed at the Conference of the Chief Ministers with the Railway Minister on 5th June, 1957.

2. The attention of the Chief Ministers was invited to the fact that a number of works had been and are being carried out in the states, such as irrigation schemes, repairing or abandoning of bunds and tanks and deforestation of large areas, which affect the safety of railway track and bridges but no intimation of this activity is given to Railway Administration. These works may considerably change the pattern of flow of flood waters across the railway line. Some of the individual railway bridges designed for the original conditions may in the new circumstances be found inadequate. If such works are located at some distance from the Railway, the Railway Administrations have no means of knowing anything about them. In the interest of safety of railways, it is imperative that Railway Authorities are kept in touch with the broad details and progress of such works by the Authorities concerned so that steps to ensure safety of track, etc., if necessary, could be taken in time.

3. There was unanimity of opinion that close co-ordination between Railways and Civil Authorities was desirable. The State Governments offered full co-operation. The consensus of opinion of the Conference was that for each State there should be a Committee consisting of senior officers from the railway(s), and Public Works, Irrigation, Forest and local self Government Departments of the State Governments who should periodically review the position of flood affecting works. If any work proposed by one department was likely to affect another, it should have the prior approval of this Committee.

4. These Committees will frame their own procedural rules but it is suggested that the Committees should hold meetings at predetermined intervals. Generally speaking, the functions might include:—

(a) Exchange of information about schemes envisaged by any one department and likely to affect the working

or safety of assets of another department and consequential safeguards to be adopted.

(b) Keeping upto date the list of railway affecting works, etc., naming the officials responsible for joint inspection of each such work immediately after monsoons and, if possible, also in advance of monsoons; and watching that the department responsible for proper maintenance of such works promptly carries out the necessary repairs.

(c) Evolving a procedure for:

(i) obtaining and broadcasting, by departments concerned, warnings or forecasts of heavy rains, floods, storms, etc., as well as the actual heavy rainfall recorded and expected floods downstream, to the officers concerned in the various Departments; and

(ii) inducing public co-operation in promptly conveying to the department concerned any unusual occurrence, *e.g.* breaches tanks, etc.

(d) Assessing whether waterways, protection works, etc. provided by any department in an area severely affected by floods have proved to be inadequate and improvements needed for future.

(e) Co-ordination of related schemes of the various departments represented.

It would thus be seen that these Committees are principally concerned with safety aspect of Railway working and also the safety of other Public Works affected by railway track, bridges, etc.

5. Will the General Managers now kindly get in touch with the State Governments concerned immediately so that these Committees are constituted and start functioning very early. The Railway Board would like to be kept informed about the progress made. A copy of this letter has been endorsed to the Chief Secretaries of State Governments.

(Sd.) H D. AWASTY,

Director, Civil Engineering.
Railway Board.

DA/Extra three copies
of the letter.

सत्यमेव जयते